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Title: Evaluation of Proposed Blast Tube Rehabilitation Measures - 30% design

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Evaluation of Proposed Blast Tube Rehabilitation Measures – 30% design

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LA-UR-22-XXXX

Analysis effort conducted to meet request for 30% rehabilitation design evaluation.

- Recent testing has resulted in deterioration of the facility
  - Multiple tube section failures and material yielding
  - Damage to support footing welds
  - Damage to underlying support structure
- Rehabilitation efforts have been proposed to improve structural response
  - Remove the underlying rail track
  - Remove the footing support and all welds along tube length
  - Replace concrete slab beneath facility
  - Support the tube sections with end saddle supports lined with rubber
- Requested modeling of the facility performance under a dynamic loading event
  - Internal explosive loading due to driver charge detonation

Simulations conducted to evaluate the effect retrofits had on QoIs of the facility response.

Evaluated QoI Metrics

- Relative axial displacement of adjacent tube sections
- Radial tube expansion
- Development of plasticity in tube and support structures

Modeling Considerations

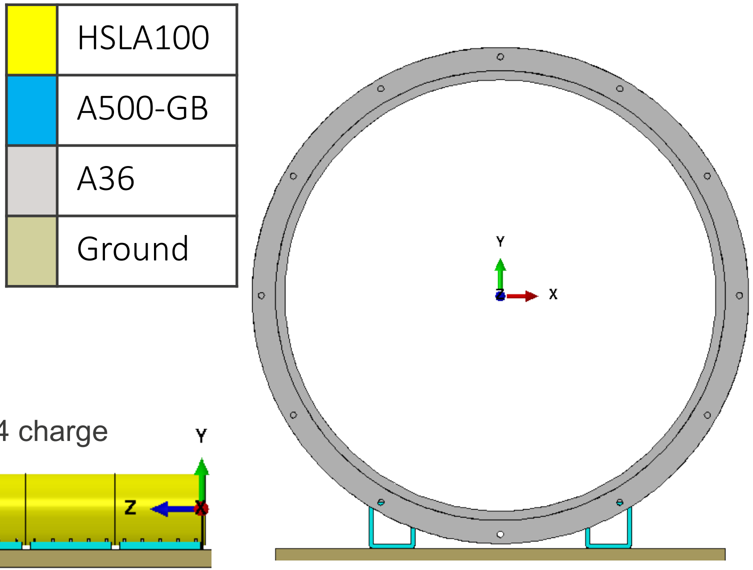
- Focused on model-to-model response comparison
- Simulations of old structural model were rerun, **with input file updates**
  - Stress bridge design at Joint 1 was replaced with 1” threaded bolt connection
- Validation of the loading and structural model has not been completed

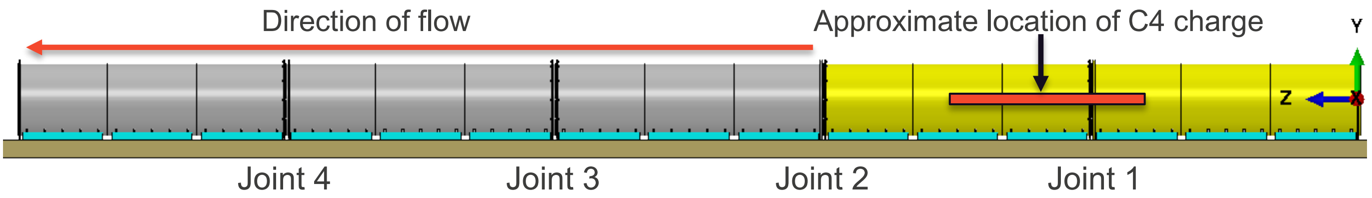
Simulations run with Abaqus 2018 HF23

Benefit of a model-to-model comparison is ability to look for changes in anticipated responses even with known modeling weaknesses which are present for each simulation.

Original structural design applied significant constraints to the motion of the facility.

- Axial bracing symmetric about center-line
  - Secured structure to legacy rail system
- Threaded bolt connection at Joints
  - Maintain tube connection during explosive event but allow for axial movement
- Footings connected to rail track
  - Exact connection methodology under question





Constraint of the system led to noticeable areas of localized stress in the facility

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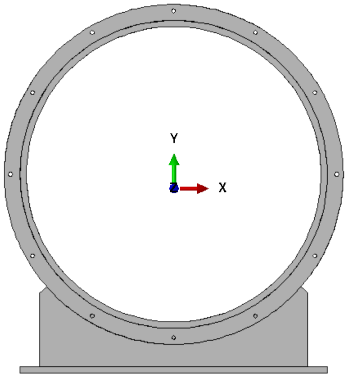
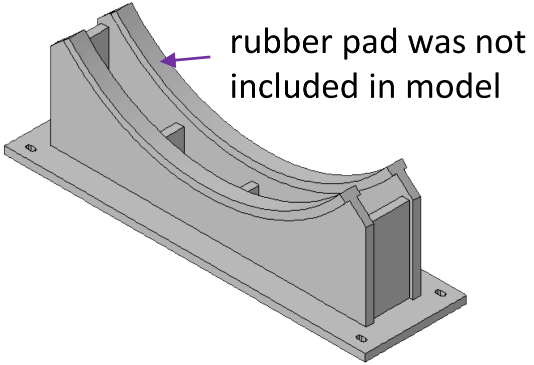
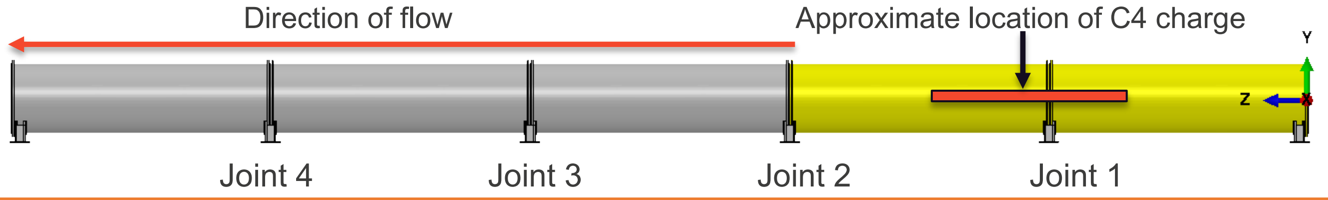
Suggested retrofits seek to remove constraints on facility and allow structural compliance.

- Axial footings replaced with saddles
  - Facility is supported only at tube joints
- Tied 3DOF saddle contact to ground
  - Exact grounding approach undefined
- Two models studied
  - Tube sections flush contact
  - ¼ “ gaps intentionally introduced into layout

(yellow)	HSLA100
(blue)	~~A500-GB~~
(light grey)	A36
(khaki)	Ground



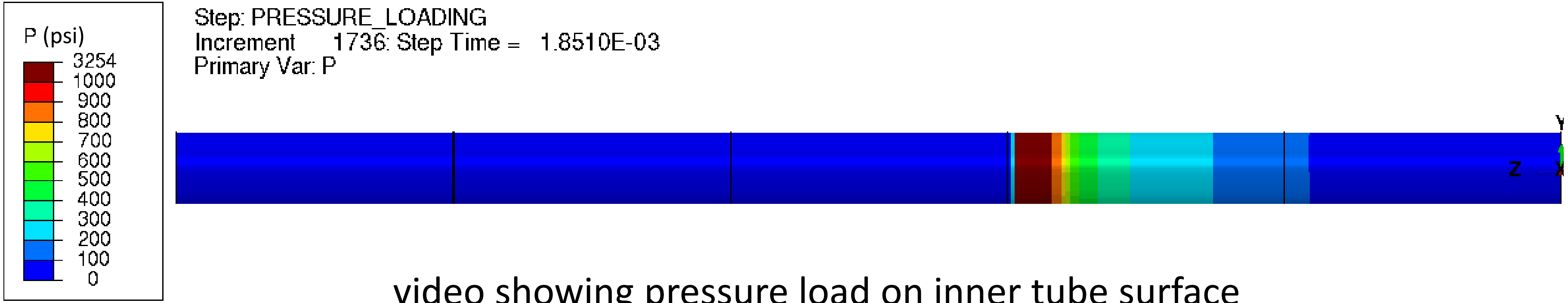




Fundamental Question: Do retrofits decrease severity of structural response and by how much?

CTH model of internal pressure load due to a 190# C4 charge used as the load condition for both models

- Loading model developed by Ronnie Parker and Keith Haberman (circa 2019)
- Pressure distribution is applied to the model via nearest neighbor technique
  - Fortran user subroutine developed by Bob Stevens (circa 2019)
- Principal focus is on response to initial detonation
  - Simulations are run for 10 milliseconds
  - Secondary shock wave begins to traverse initial tube section



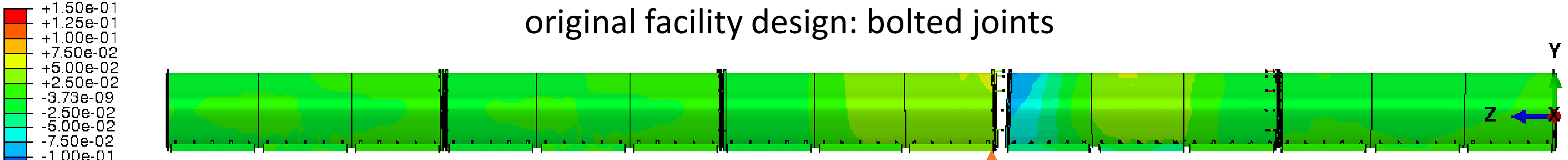
video showing pressure load on inner tube surface

Significant differences noted in axial facility response due to constraint updates

deformation magnitude: x100
5.9 ms post-detonation

U3 [in]

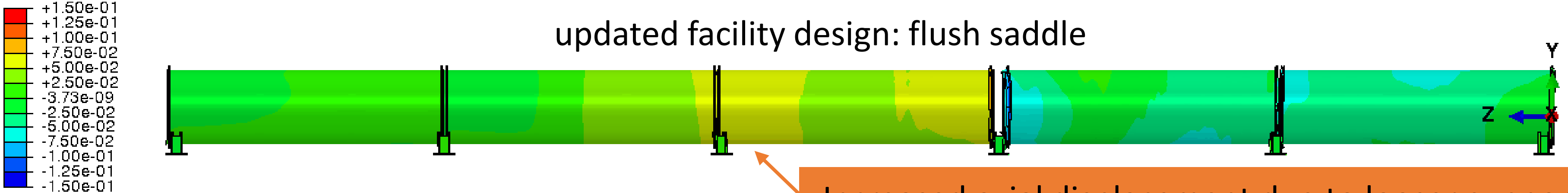
original facility design: bolted joints



collision sends shock down remaining facility

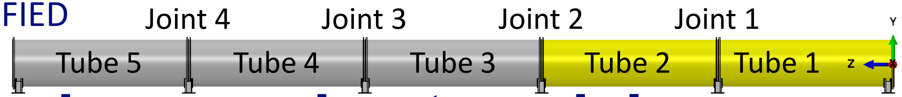
U3 [in]

updated facility design: flush saddle

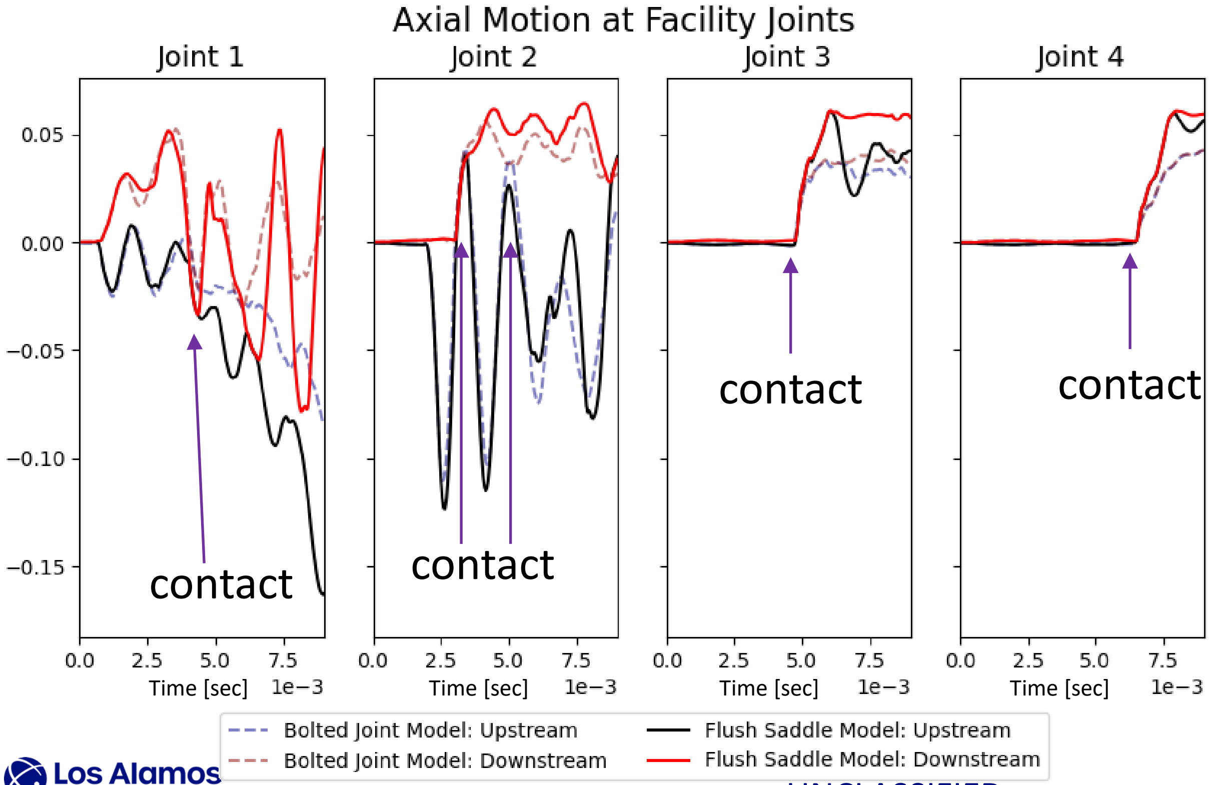


Increased axial displacement due to looser support

video showing axial displacement of structure



Contact between tube sections is seen due to axial elongation / contraction caused by Possion's effect

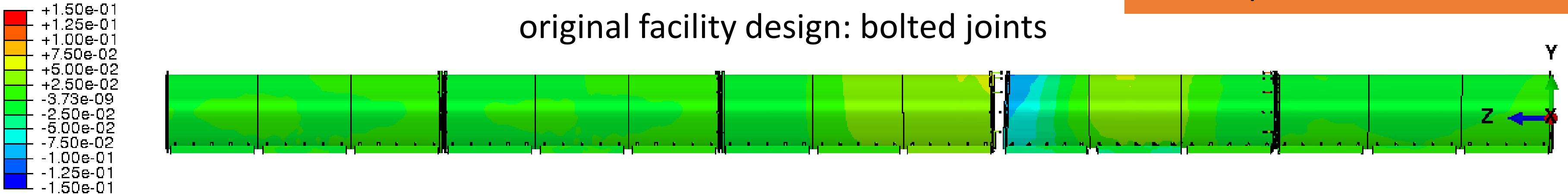


- Contact seen in all joints
- Larger displacements
  - Removal of axial constraint
  - Increased movability
- Opening of gaps anticipated
  - ¼" in Joint 1 (late time)
    - Reflected wave

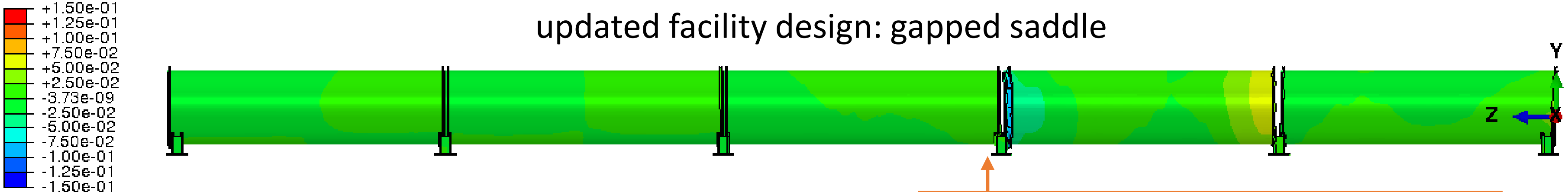
Introduction of ¼" gaps show significant difference in facility axial response

deformation magnitude: x100
5.9 ms post-detonation

original facility design: bolted joints

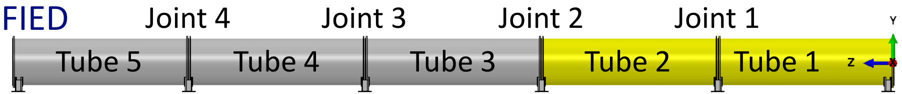


updated facility design: gapped saddle

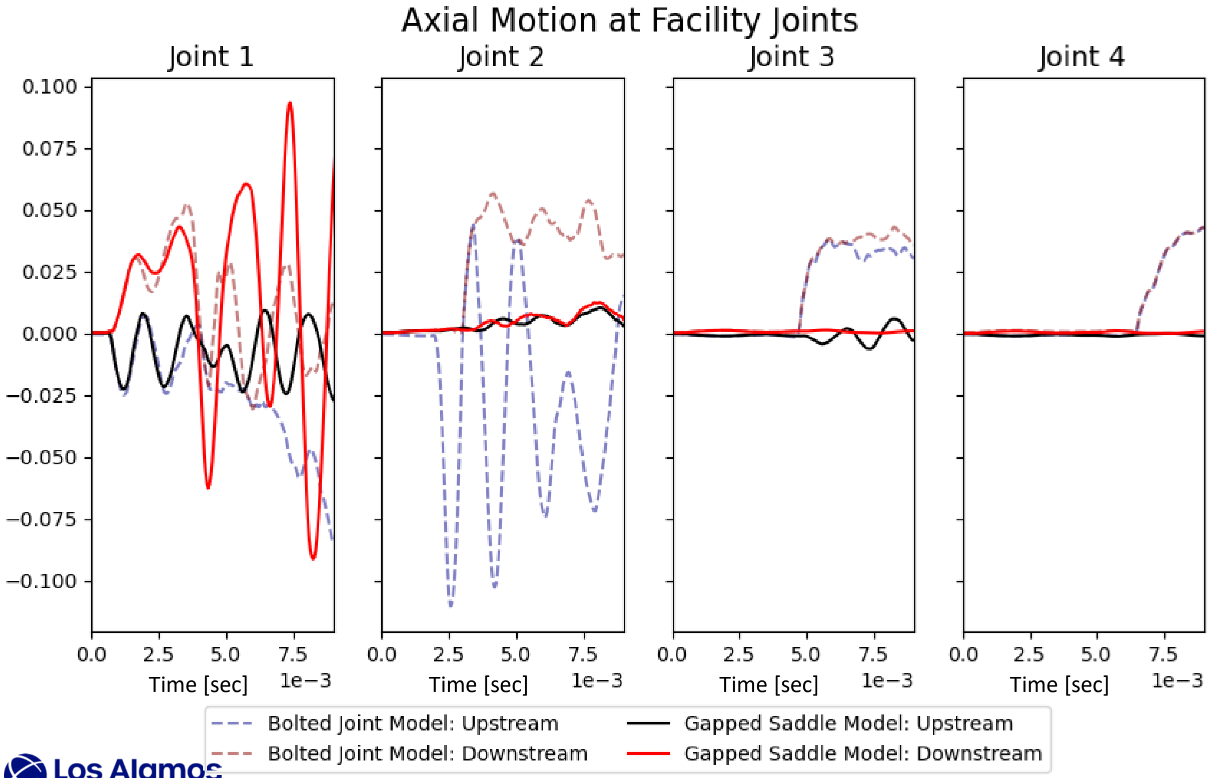


No visual evidence of tube collision

video showing axial displacement of structure



¼" gap between tube sections alleviates contact between tube sections



- Spacing of tube section eliminates interference
  - contact is not seen due to gap
- minimal downstream movement
  - gap may be unnecessary for downstream sections

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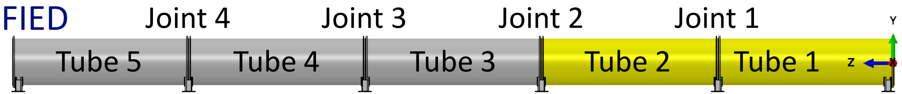
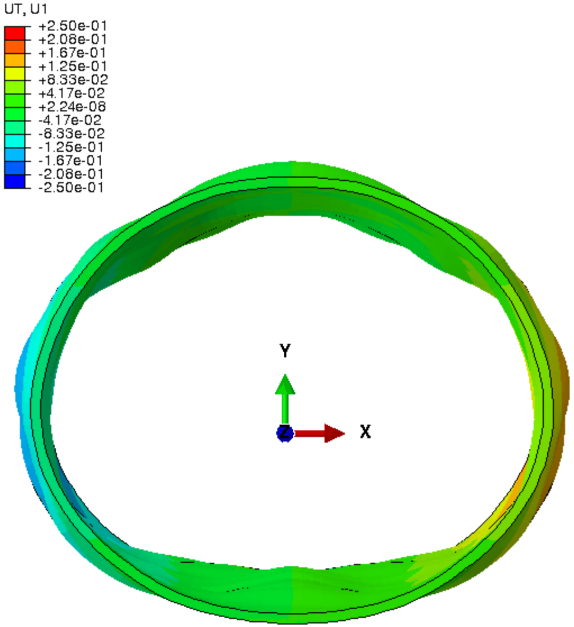
videos showing radial displacement of Tube 2

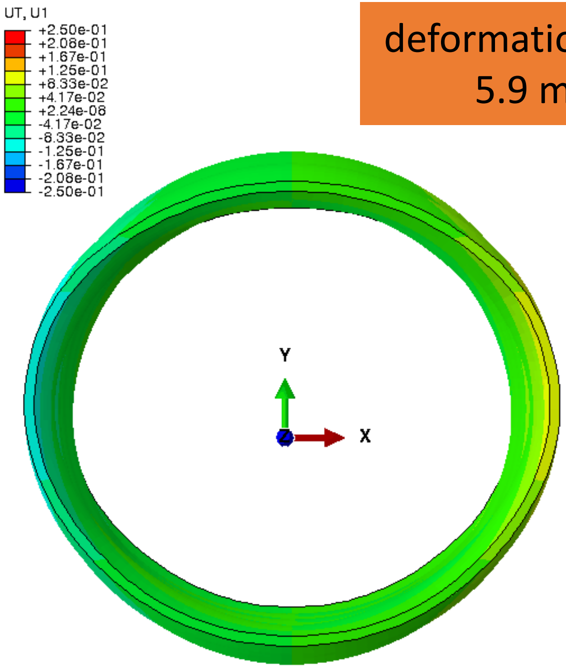


Effects of proposed rehabilitation on radial expansion show evidence of improved dynamic response.

deformation magnitude: x50
5.9 ms post-detonation



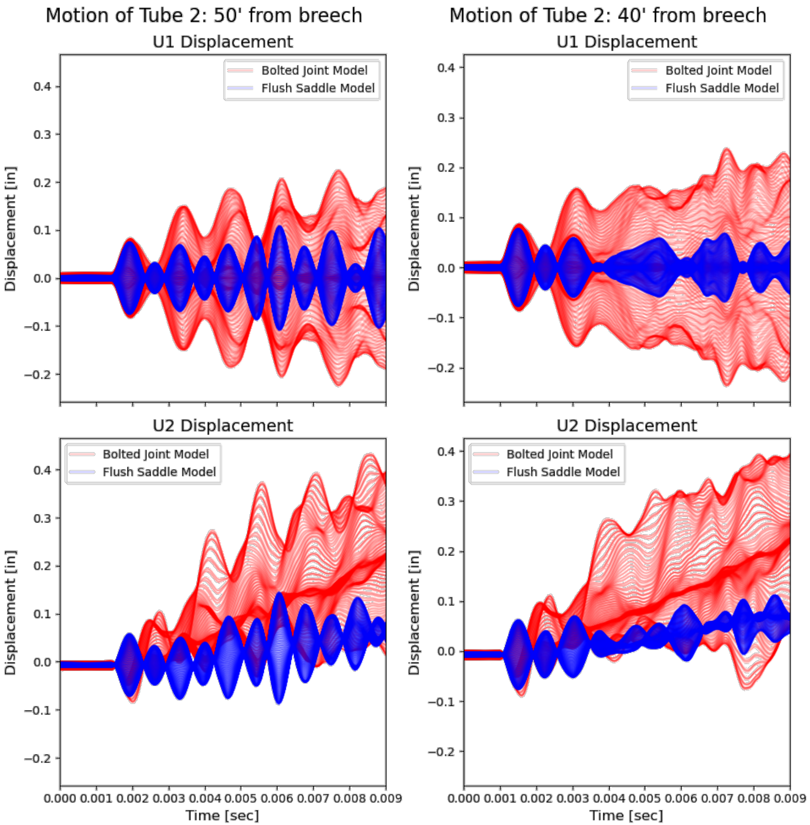
original facility design: bolted joints



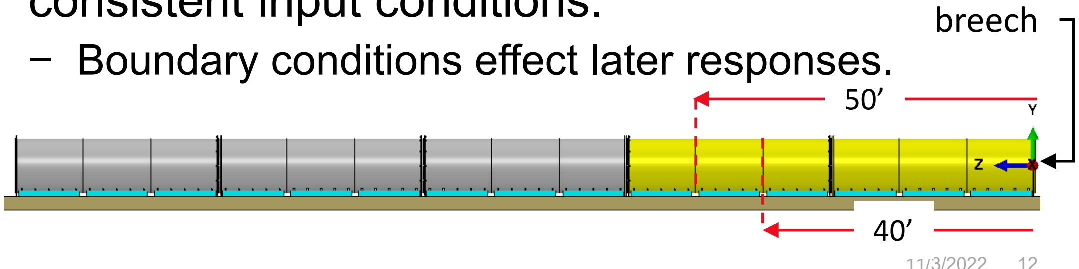
updated facility design: flush saddle

U1 – horizontal motion | U2 – vertical motion

Significant changes in radial displacements noted



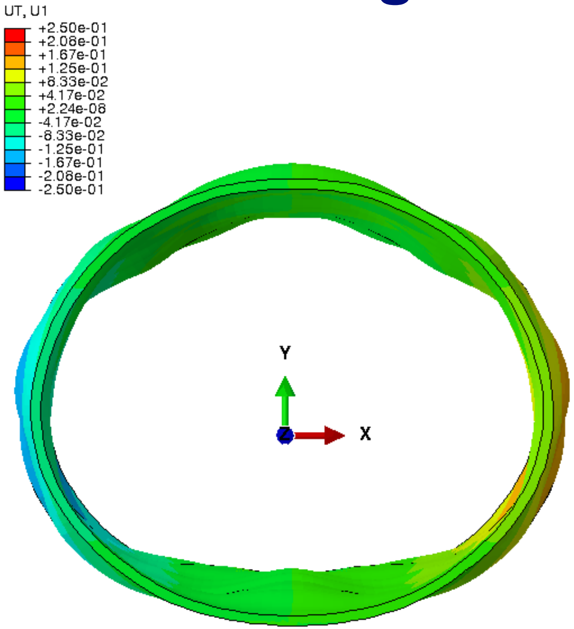
- Displacement at joints have been attenuated
  - Hypothesis that more energy is going into the overall radial expansion of the tube sections
- Tube ‘jump’ has also been attenuated
  - Location of reaction forces has shifted to saddles
- Interference of multiple wave patterns suspected.
- Similar initial response of models speak to consistent input conditions.
  - Boundary conditions effect later responses.



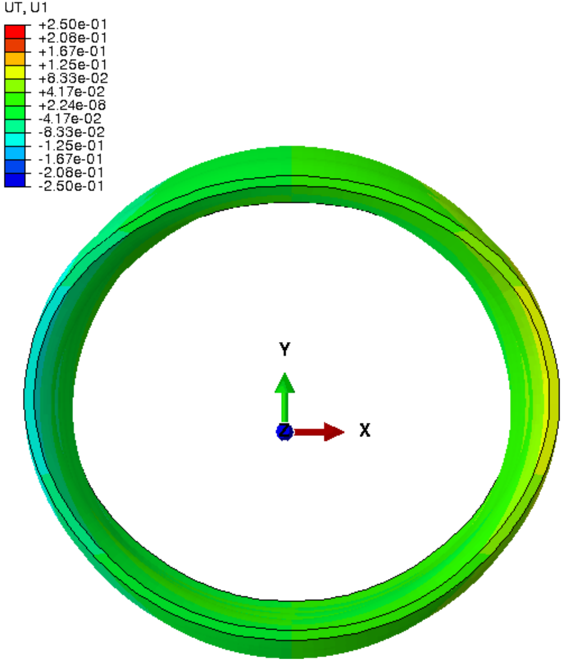
videos showing radial displacement of Tube 2

Minimal change in radial response seen between the saddle designs.

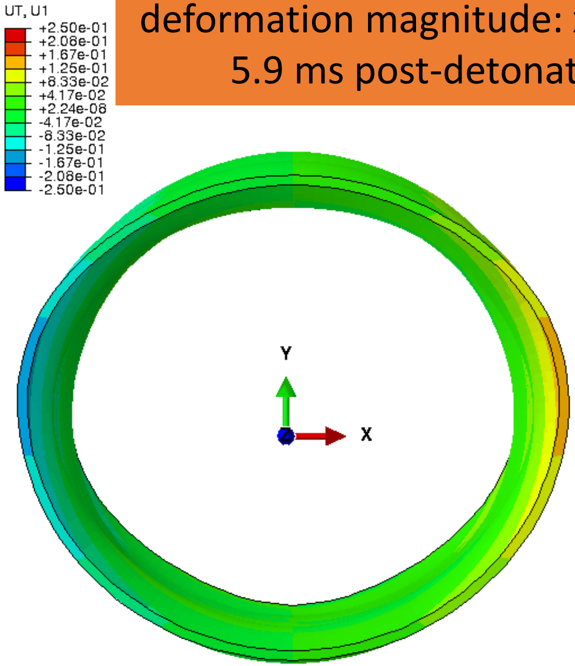
deformation magnitude: x50
5.9 ms post-detonation



original facility design:
bolted joints



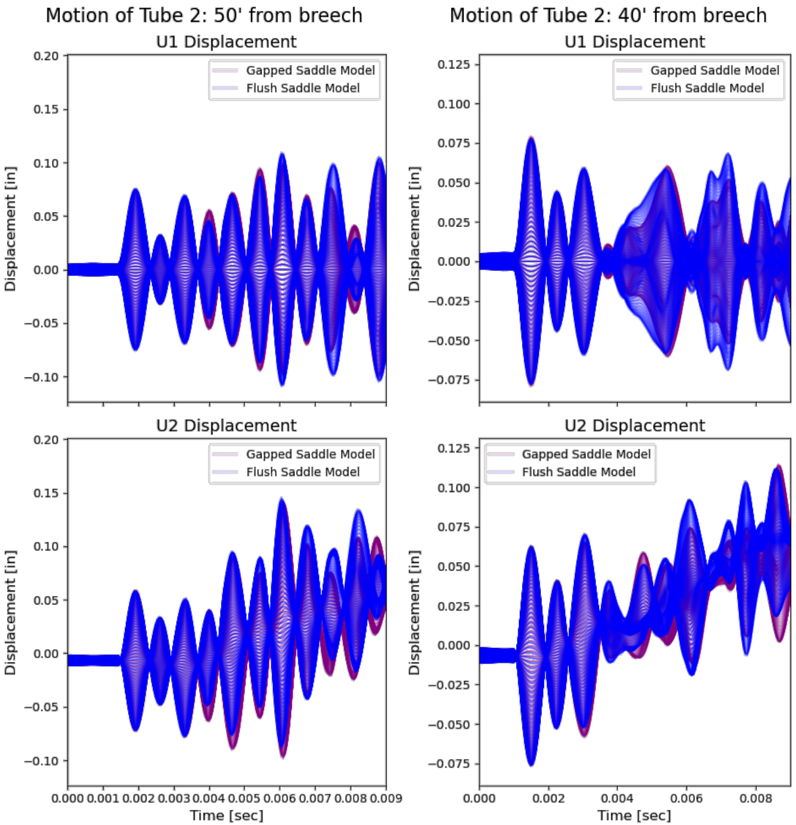
updated facility design:
flush saddle



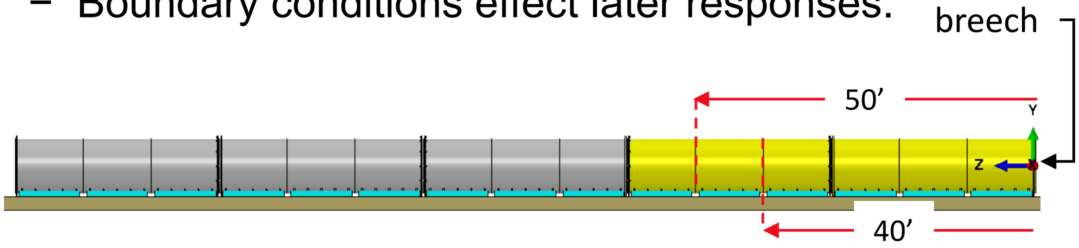
updated facility design:
gapped saddle

U1 – horizontal motion | U2 – vertical motion

Flush design does lead to multiple wave signals



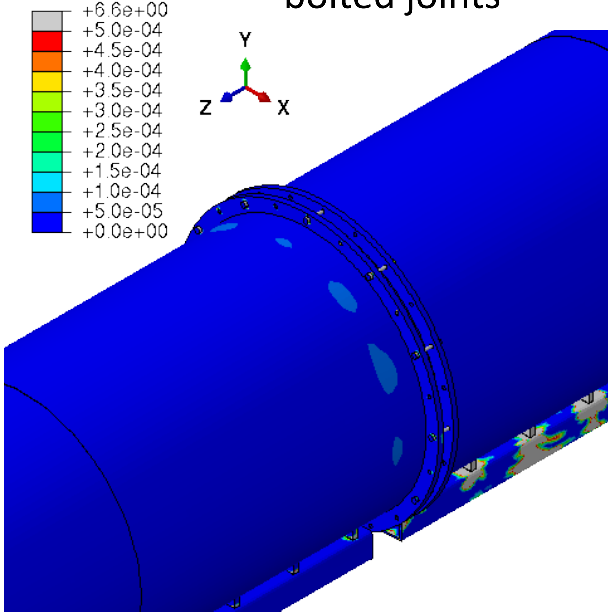
- Time signals are largely consistent
  - Loading is dominating tube response
- Later time response (4ms) shows variability
  - Hypothesis of multiple waves moving through tube after impact in flush design
- Interference of multiple wave patterns suspected.
- Similar initial response of models speak to consistent input conditions.
  - Boundary conditions effect later responses.



Material yielding is still present in facility with proposed rehabilitations.

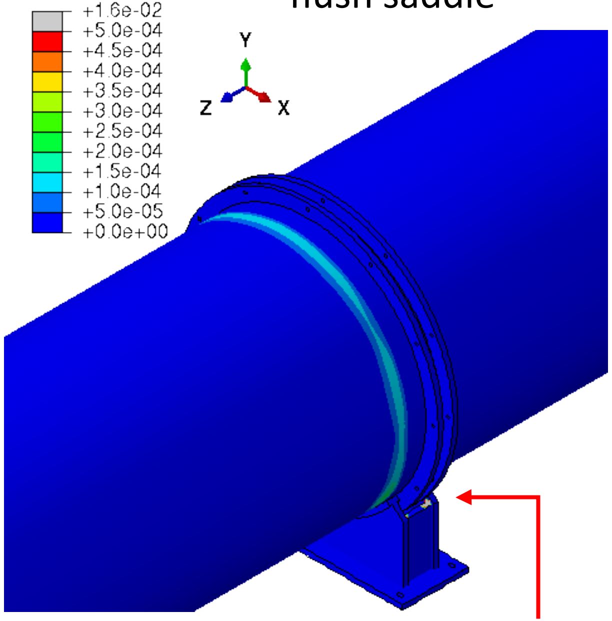
Equivalent Plastic Strain: in/in

original facility design: bolted joints



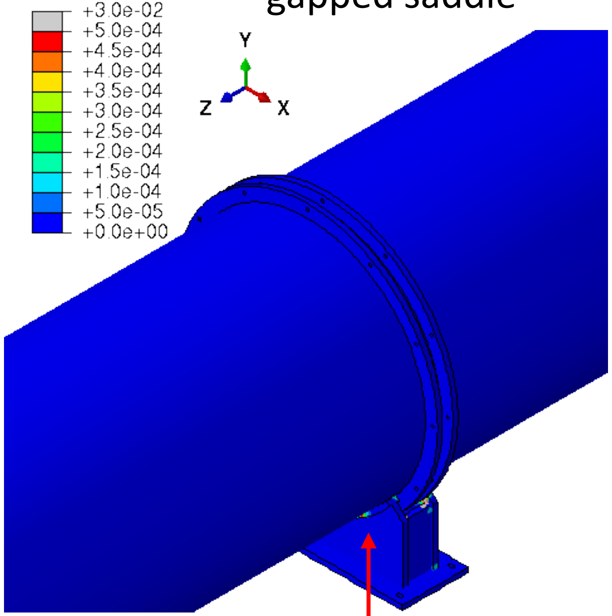
Equivalent Plastic Strain: in/in

updated facility design: flush saddle



Equivalent Plastic Strain: in/in

updated facility design: gapped saddle

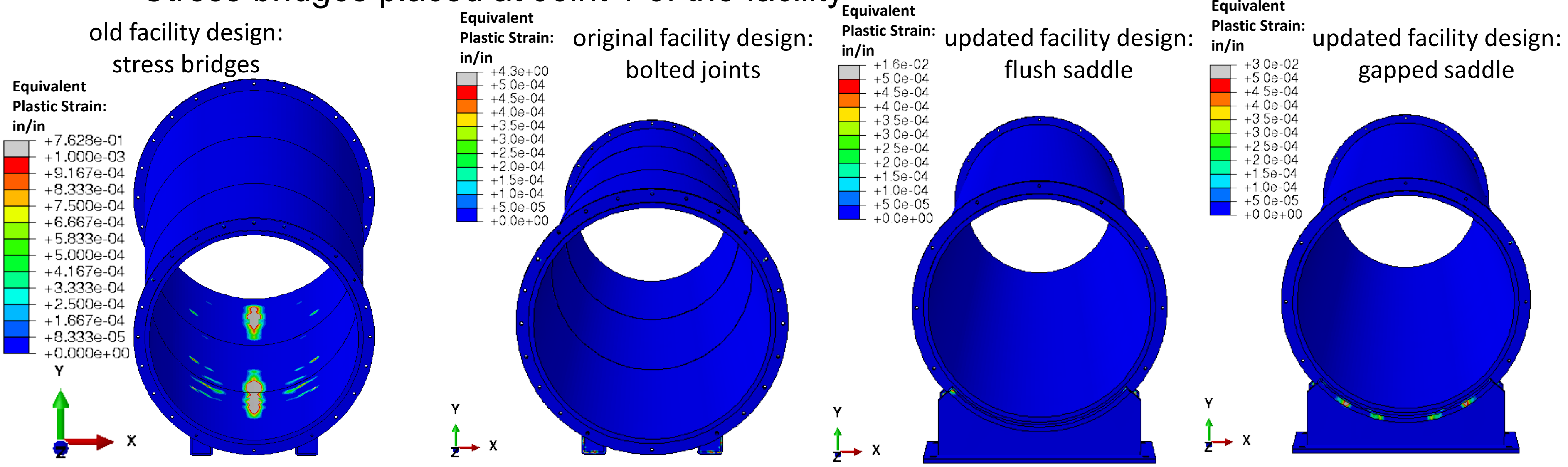


Plasticity noted in the saddle

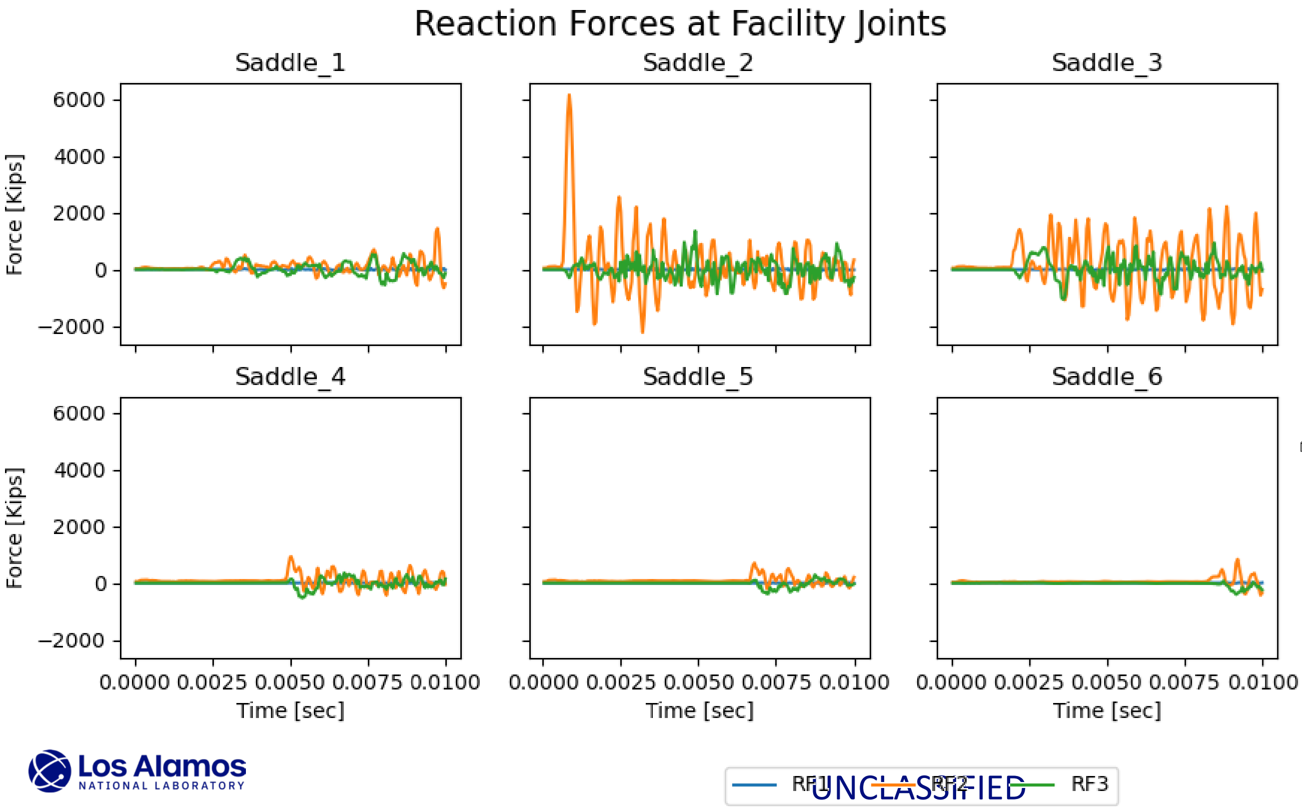
Further modifications to design needed to remove plasticity from saddle support.

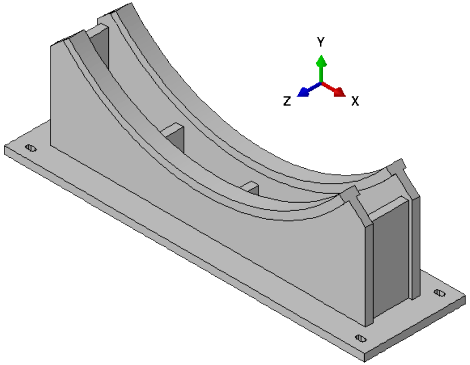
Plasticity in the tube section is not seen for current facility design and proposed rehabilitations.

- Model that resulted in plasticity of the tubing had several considerations
  - Like materials for both the tube and footing designs.
  - Stress bridges placed at Joint 1 of the facility



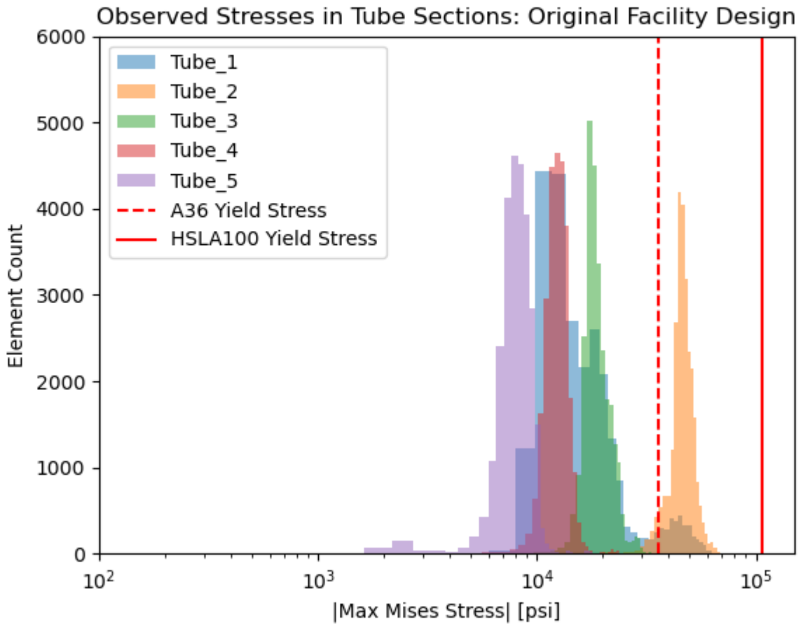
Reaction forces were evaluated for the flush saddle design. Model shows high forces at Joint 2 support

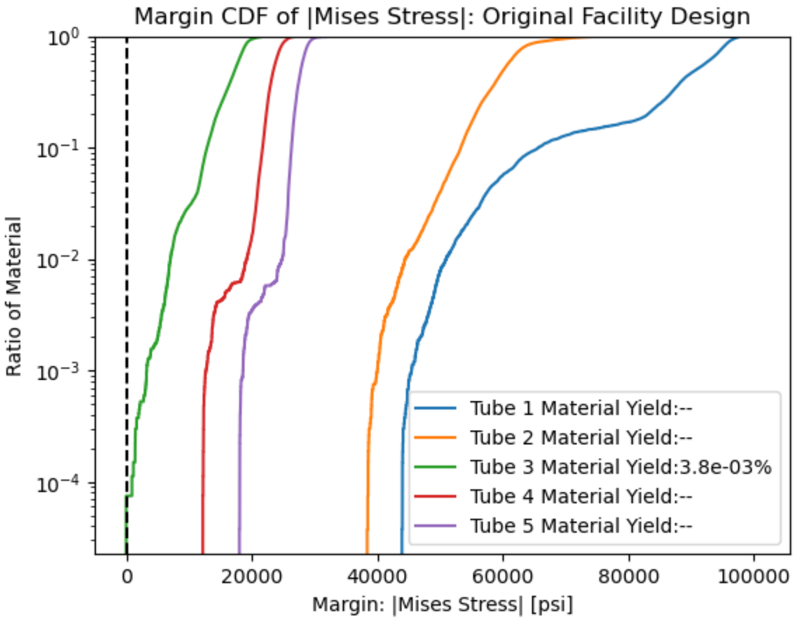




Magnitudes of $|\text{mises stress}|_{max}$ show limited material yielding in Tube 3

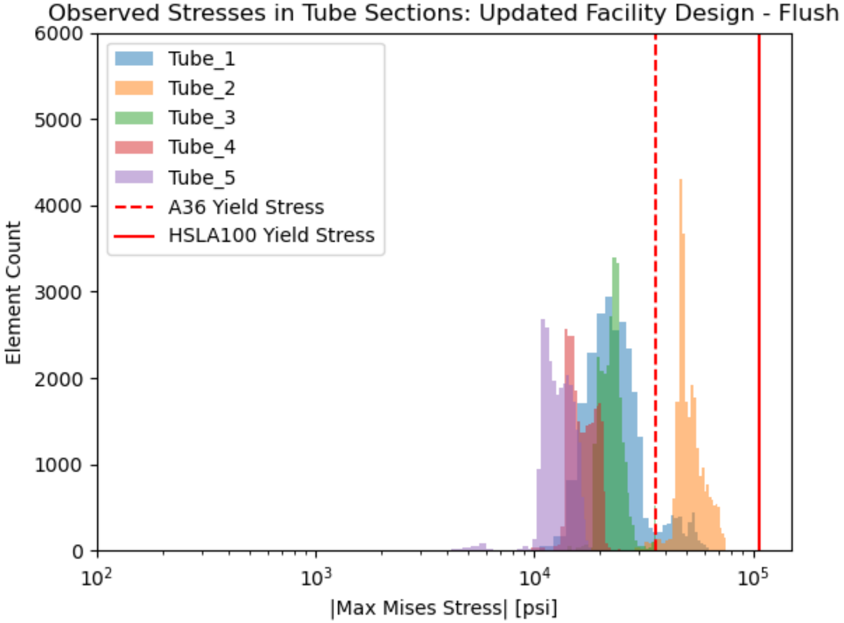
Original facility design: Bolted Joints

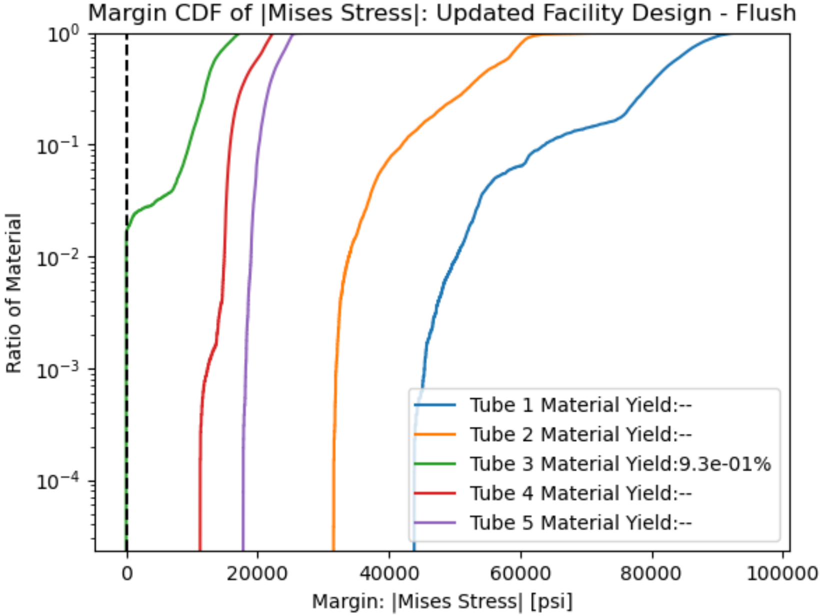




Magnitudes of |mises stress|$_{max}$ in flush tube design show higher stresses in bulk material

Updated facility design: Flush Saddle

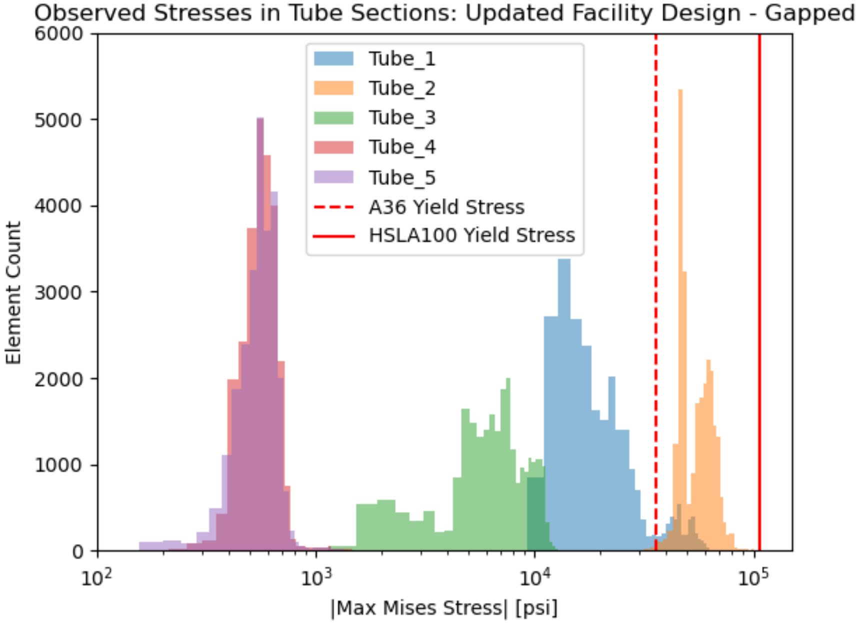


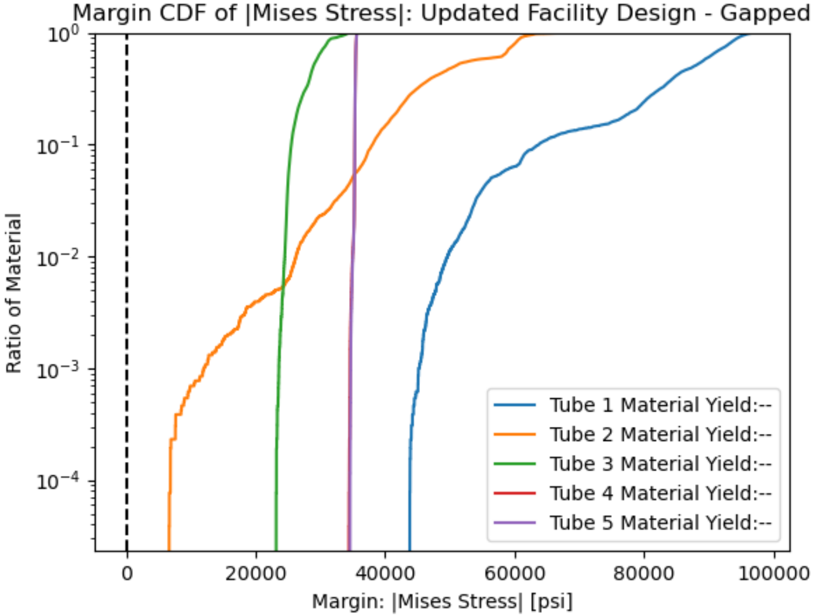


- Maximum stresses in HSLA100 tubes show increase ~ 5%
- Maximum stresses in A36 tubes increase by an average 2%

Magnitudes of |mises stress|$_{max}$ show changes to tube response if gaps are introduced

Updated facility design: Gapped Saddle

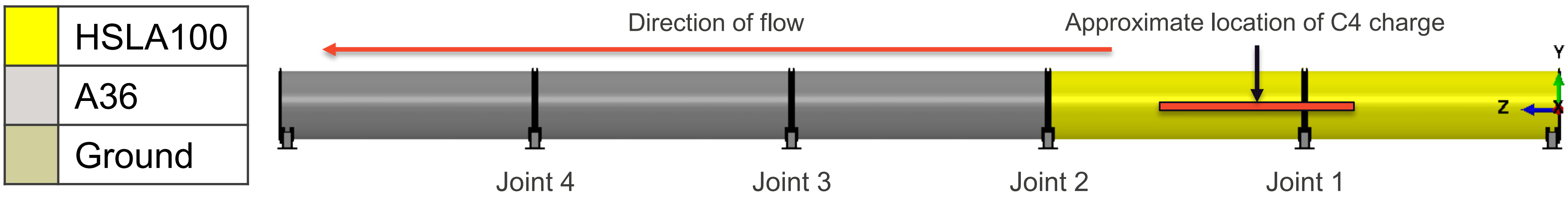




- HSLA100 tube sections show minimal change in maximum stress
- A36 tube sections see dramatic decrease in max stresses ~ 83% drop

Assumptions and uncertainties in modeling should be investigated as rehabilitation designs mature.

- Validation of loading model
  - CTH input files are not accessible for analysts to investigate
- Asymmetric loading of the facility
  - Uncertainty of charge placement variability on structural response
- Influence of past loading on future structural response
  - Restart files could be used to investigate multiple loadings



Next Steps / Proposed Path forward

- Investigate different cradle configurations
  - Central support, modified tube connection
  - Recommendation against ratchet straps in favor of support modifications to protect against roll off.
- Investigate effect of friction coefficient on saddle plasticity development
- Study possibility of decreasing gaps at downstream joints
- Can tube sections be built out of differing materials rather than HSLA-100?
- Extend simulation to capture late time responses
- Simulate unconstrained tube structure – ideal case
- Utilize restart files to attempt investigation of tube damage effects
- Investigate tube gap effects on shock wave behavior

Results show improvements in overall facility response. Options exist for additional improvements